Studies on color in plants*

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The subject of color may be viewed in a number of ways. The physicist considers colored substances in their relation to light, and defines color as due to the influence which the substance has upon the vibration of the ether-waves and as dependent upon physical conditions. The chemist is interested in the constitution and composition of the colored substance, while the biologist is concerned with its origin and the role which it plays in metabolism or the life-processes of the plant or animal. The nature of *color in plants and animals* is more or less distinct, and while a number of animal pigments have been isolated, as cochineal and lac-dye, the color effects in animals are due largely, especially in the plumage of birds, to physical structure, *i. e.*, light interference phenomena or the dispersion of light rays. While structural arrangement in plants has also an influence on the color effects, still the colors in plants are usually looked upon as being due to distinct chemical principles without special reference to physical structure.

Upon making a section of some colored tissue of the plant, we find cells containing two or more of the following substances. In the first place there is in the living cell a semi-fluid, viscous, granular or foam-like substance known as *protoplasm*, of which, as regards its chemical composition and function, we know little more than when it was first described by von Mohl in 1846. This lies either close to the walls of the cell, forming a relatively thin layer or lining, which encloses a large vacuole of cell-sap, or it may be distributed in a mesh-work, forming smaller vacuoles. Within the protoplasmic mass we find a differentiated body known as the *nucleus*, and in recent years much of the work done by biologists has been devoted to a study of this body. There are in addition other protoplasmic bodies found in the plant cell, known as *plastids*,

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which are much smaller than the nucleus and are distributed through the protoplasm in relatively large numbers. Of these there are two distinct groups, one containing a green pigment, which gives the green color to leaves, known as the *chloroplastid*, and the other containing a yellow pigment, which gives the yellow color to yellow flowers and fruits, known as a *chromoplastid*. In the vacuoles already referred to occur various coloring principles which are dissolved in the cell-sap and which give the various colors other than yellow to flowers and fruits, as blue in the violet or plum, red in the carnation, rose or apple, etc.

PLASTIDS AND PLASTID COLOR-SUBSTANCES

Regarding the structure of the plastids we know but very little. In all cases they consist of a protoplasm-like substance in which is held either mechanically or in chemical combination the green or yellow coloring principle. The *chloroplastids* in addition contain starch-grains, which are considered to be manufactured by the chloroplastid under the influence of sunlight from water and the carbon dioxide of the air; they may also contain proteid substances and oil. While the protoplasm has been termed by Huxley "the physical basis of life," this little chloroplastid, but the one five-thousandth of an inch in diameter, has been spoken of as the mill which supplies the world with its food, for it is by the process of photosynthesis that the energy of the sun is converted into vital energy, and starch and other products formed, which become not only the source of food for the plant itself, but also the source of the food-supply of the animals which feed upon plants. In other words, horse-power is derived from the energy of the sun which is stored by the chloroplastids in the plant.

In the *chromoplastid*, on the other hand, there are usually present, as first pointed out by Schimper and Meyer, protein substances in the form of crystal-like bodies; starch-grains may also be present. The chromoplastids are very variable in shape and in other ways are markedly different from the chloroplastids. They are more unstable than the chloroplastids, are formed in underground parts of the plant, as in the root of carrot, as well as in parts exposed to the light, as in the flower. Their formation frequently follows that of the chloroplastids, as in the ripening of certain yellow fruits, such as apples, oranges, persimmons, etc.

The *plastid pigments* are distinguished from all other color-substances in the plant by the fact that they are insoluble in water and soluble in ether, chloroform and similar solvents. This seems to be a wise provision, as it probably prevents the diffusion of these principles in the more or less aqueous cell-sap. These plastid pigments are but little affected by the usual chemical reagents under ordinary conditions.

Apart from the difference in color, the yellow pigment is distinguished from the green by the fact that the latter is said to contain nitrogen, and also by their difference in behavior when examined spectroscopically, chlorophyl giving several distinct bands in the yellow and orange portion of the spectrum, which are wanting in the spectrum of the yellow principle.

The leaf-buds of the skunk cabbage are quite large, consisting of numerous leaves. The innermost leaves are of a distinct yellow color. A microscopical examination of these shows that the color is due to a plastid which is very much smaller than the chloroplastids or chromoplastids found in the fully developed leaves and flowers of the plant. This plastid occurs in the palisade cells and contains neither starch nor proteid substances, and the yellow pigment appears to be somewhat similar to that found in chromoplastids, but differs in this, that on reducing with zinc it becomes slightly greenish. This plastid, which I have provisionally termed an *etioplastid* (and the pigment *etiophyl*), appears later, with the development of the leaf, to be transformed into a chloroplastid, whereas just the reverse takes place with chromoplastids, that is, they may be derived from chloroplastids. I may further say with regard to the pigment etiophyl, that on purification and treatment with zinc it appears to be entirely distinct from chlorophyl when viewed both by transmitted and reflected light and when examined by means of the spectroscope. It is also characterized by its greater stability even when exposed to light, and may be partly separated from chlorophyl in an alcoholic solution (85 per cent. alcohol) by means of benzin. An interesting observation which I have made in this connection is that when leaves of skunk cabbage containing both etiophyl and chlorophyl are extracted with alcohol, purified, and reduced with zinc, the resulting solution is a deep green and retains this color.

CELL-SAP COLORS

All the other color-substances found in plants besides the green and yellow principles just mentioned occur in the cell-sap, and may be in the nature of secondary substances derived from the plastid pigments, or they may be produced directly by the activities of the protoplasm. During the course of my work I have been much impressed by the fact that in tissues containing cell-sap color-substances, or as they might be termed *unorganized color-substances*, not infrequently strikingly contrasting colors are observed in contiguous cells; as in the petals of the poppy and petals of certain lilies, where we find some cells of a deep-purple, others of a deep-red and still others of intermediate shades. The same may be said of the germinating kernels of black Mexican corn. This observation has led me to believe that the shades of color in the pigmented cells are largely dependent upon the nature of the substances associated with the fundamental color-substance. The unorganized color-principles are easily extracted with water or dilute alcohol. I have examined the principles from several hundred plants, and find that they are all more or less affected by certain chemicals (many of which occur naturally in the plant), such as citric acid, oxalic acid, salts of calcium, iron, aluminum, etc.

A solution of the mallow flowers of the garden is of a purplish-red color and becomes green with lime water; deep-red with oxalic acid; purplish-red with alum; and deep brownish-red with ferric chloride.

A solution of rose petals (J. S. Fay) is of a more or less light-brown or pale yellowish-red color and becomes pure green with lime water; deep yellowish-red with oxalic acid or citric acid; purple with alum; and deep-blue with ferrous sulphate.

These reactions show that these color-substances are quite sensitive to the influence of chemicals, and many of them correspond to the class of substances known as indicators; in fact a number of plant pigments are used as indicators in volumetric chemical analysis, their use in this connection being dependent upon their sensitiveness to acids and alkalies. The fact that they respond to iron salts, that is, give a blue or green reaction with these salts, would indicate that they are associated with tannin or that they are tannin-like compounds, as has been supposed by

some writers. It may therefore be of interest to compare the reactions of tannin with those already given.

A solution of tannin, which is colorless, produces no color with lime water, with acids, or with alum; becomes deep-blue with ferrous sulphate, which is rather characteristic, and reddish-brown with alkalies. It is thus seen that tannin behaves very differently toward these reagents except in the case of iron salts.

An examination of the color-substances of a large number of plants shows that the flower color-substances are distributed in all parts of the plant. For example, the flower color-substance of the rose occurs in the leaves and prickles as well as in the petals, and this substance can be readily separated from the chlorophyl associated with it in the leaves by treating an alcoholic extract of the leaves with benzin.

In an alcoholic extract which has been so treated, the benzin layer at the top contains the separated chlorophyl and the alcoholic layer at the bottom contains the flower color-substance, which becomes more distinct by the addition of reagents.

The color-substance in the root of the radish closely corresponds to that in the flowers, and the color-substance in the grains of black Mexican corn corresponds to that in corn silk.

An extract of black Mexican corn shows reactions with chemicals closely resembling those obtained with various flower color-substances, as of rose.

The solution of black Mexican corn, which is of a reddish-purple color, rapidly changing to purplish-red, becomes green with lime water; red with oxalic acid; purple with alum, which is quite pronounced; and distinct blue with ferrous sulphate.

The cell-sap color-substances are usually found in greatest amount at the tips of the branches, this being well marked in the foliage of the rose, and may be said to be rather characteristic of spring foliage. Not infrequently in the purple beech the young leaves will be of a distinct purplish-red color and almost entirely free from chlorophyl, suggesting a correspondence in position and color to a flower.

The results of my work further seem to show that there is a fundamental cell-sap color-substance which occurs in two modifications in the plant, one becoming yellowish-red and the other pur-

plish-red with acids. These two modifications may occur in the same part of the plant, as in the petals of the poppy, or in widely separated parts, as in radish, where the substance which becomes yellowish-red with acids occurs in the root, and the one which becomes purplish-red occurs in the flower.

Inasmuch as these two modifications behave in addition differently toward other reagents, they might be said to show an analogy to some of the sugars, as well as other substances, of which two modifications occur.

The existence of two modifications of the fundamental cell-sap color-substance is well exemplified in the case of roses, some fifty sorts having been examined. The color-substances extracted from deep-red or crimson roses give a yellowish-red color with mineral acids, a deep-blue or purple with potash-alum, ferric chloride or ammonio-ferric alum. The solutions obtained from pale-red or pink roses give a purplish-red with mineral acids, a pale-purple or pale purplish-brown with potash alum, and olive-green with ferric chloride or ammonio-ferric alum. With some of the hybrid tea roses and some of the yellow roses intermediate tints are obtained by the use of these reagents corresponding to the colors in the parent plants.

COLOR IN AUTUMN LEAVES

The coloring matters in both spring and autumn leaves closely resemble the cell-sap color-substances of flowers, although it is the spring leaves which give the most satisfactory results. The fact that in the autumn leaves there is little or none of the plastid pigment present would point to the conclusion that the color-substances occurring in these leaves are in the nature of by-products and of no further use to the plant. Of course in the case of autumn leaves we know that these products cannot be further utilized, and for this reason we are justified in regarding them as waste products.

COLOR IN MARINE ALGAE

The marine algae offer interesting material for the study of vegetable color-substances, and probably will be found to throw some light on the subject of the origin of color in plants. The plastids are numerous, constituting a large proportion of the components of the cell. They are variously colored, being red in the red algae,

brown in the brown algae, etc. The color-substances are more or less difficult to extract. The *chlorophyl* can be extracted by the use of absolute or 95 per cent. alcohol, except in the case of some of the more delicate red forms like *Griffithsia*, *Dasya*, *Grinnellia*, *Callithamnion*, *Agardhiella*, etc., where it is necessary to place the material direct from sea-water into a saturated solution of sodium chloride and afterwards treat with alcohol.

While the *red and brown color-substances* are for the most part difficult to extract, still some of them can be extracted quite easily with water or dilute alcohol, and these show an analogy in their behavior toward reagents to the cell-sap color-substances of the higher plants.

It would appear from a microscopical study of the marine algae that all the color-substances arise in the plastids. The difficulty in extracting these substances in most cases leads to the supposition that either owing to the composition of the plastid or of the cell-sap, the color-substances are held by the plastids and not diffused in the cell-sap as in the higher plants, *i. e.*, the cell-sap color is held in the vacuolules of the plastids.

PRESERVATION OF PLANT SPECIMENS

The fact that the red and brown coloring substances of these marine algae were held back or rendered insoluble by the use of a saturated solution of common salt, suggests the use of this solution as a preservative of not only marine algae, but also of fruits, flowers and vegetables for study or exhibition purposes. Specimens have been preserved in this manner, some of them for more than a year. I may add, however, that not all specimens can be preserved with salt solution.

EXPERIMENTS IN CONTROL OF COLOR IN PLANTS

That the color in plants is influenced by a number of factors, including light, temperature and soil, is well known. One of the most common examples showing the influence of light is furnished by certain sorts of apples, those portions of the fruits exposed to the direct sunlight being most highly colored. The influence of temperature on the color of plants is also illustrated by the highly colored red apples of higher latitudes. It is a matter of general

observation that the intensity of color is in direct ratio to the amount of sunlight and coolness of temperature, that is, of course, within certain limits. On the other hand, high temperature and diminution of light tend to decrease the intensity of color. The combined effect of sunlight and coolness of temperature is also seen in the foliage of the plants of alpine regions and higher latitudes, as well as in the spring and autumnal foliage of plants in the temperate regions.

The supposition that certain constituents of the soil perceptibly modify the color of plants probably dates from the experiments of Risse, who found that the so-called "zinc-violet," a blue-flowered form of *Viola lutea* (one of the alpine violets of Europe), grows in a soil containing 20 per cent. of zinc oxide, and that the ash of the plant contains as much as 1 per cent. of zinc oxide. The fact that this "zinc-violet" maintains the blue color when transferred to a soil which does not contain zinc, together with the fact that the color varies when grown in a soil containing zinc, led Hoffmann to conclude that the presence of zinc had no influence on the color. On the other hand, it is commonly supposed that the blue color of hydrangea is due to the addition to, or presence in, the soil of certain chemicals, as alum or iron filings. It is also a common practice among rose growers to treat the soil with a solution of copperas or ferrous sulphate (approximately 1 part of salt to 1,000 parts of water) in order to intensify the color of red roses. But curiously, the same treatment appears to decrease the intensity of color in the pale-red roses.

The fact that plant color-substances are modified to a greater or less extent by certain chemicals, as already indicated, led to the idea that it might be possible to influence the color-substances in plants by feeding the plants with chemical substances. The creation of color-principles is quite another problem.

During the past year I have been experimenting with roses, carnations and pansies, using the following chemicals: Acetic acid, citric acid, malic acid, phosphoric and other acids; various iron salts, as the acetate, citrate, chloride, sulphate, etc.; certain aluminum salts, as sulphate, phosphate, and the double salts of aluminum and potassium sulphate and aluminum and ammonium sulphate; ammonia water, potassium hydrate, ammonium nitrate,

potassium nitrate, potassium iodide, iodine, potassium cyanide, etc. These chemicals were supplied to the plants through the soil, beginning with a strength of 1 part of chemical to 10,000 parts of water. The strength was gradually increased until that of 1 part of chemical to 1,000 parts of water was reached. It was found that most of these chemicals could be supplied in this strength every five days for some months without injury to the plants. In other words, each plant could be supplied with 75 milligrams of chemical every five days without injury. With the exception of solutions of iodine and potassium iodide, and of potassium cyanide, it was found that a plant in a six-inch pot could be supplied with as much as 300 milligrams of chemical, an equivalent of 150 c.c. of a solution containing 1 part per 500 every five days. It was also found that plants growing in garden soil could be treated with a stronger solution of chemical than those growing in either sand or artificial soil. Plants which would stand treatment with a solution of potassium cyanide, 1 part to 1,000 parts, when growing in garden soil, were killed by a solution of this strength when growing in sand or an artificial soil.

RESULTS OF COLOR-CONTROL EXPERIMENTS

So far as I have been able to see, the treatment with the color-control solutions has not produced any marked effects. Some slight changes have been noted, but these could perhaps be ascribed to other causes as well as to the solutions. For instance, it was noted that in yellow roses supplied with aluminum and potassium sulphate the leaves and stems were slightly reddish and the flowers a deeper yellow than others, while those supplied with potassium hydrate were paler than the type. In the case of the La France rose plants supplied with iron citrate and citric acid the petals were of a uniform pink color.

The inner petals of plants supplied with iron malate and malic acid were pale in color, while the inner petals of plants which were supplied with either formic acid, ammonium nitrate, or iron salicylate and salicylic acid were of a deep-pink color. In the case of maroon roses, the petals tended to a deep purplish-red when treated with potassium cyanide or potassium nitrite; to a dark-red when supplied with phosphoric acid, iron and ammonium

sulphate, or sulphuric acid. In fact the color of the maroon roses approached that of the crimson roses when treated with sulphuric acid, and they also tended to singleness.

The scarlet carnation, when supplied with any of the following chemicals, showed a tendency to form white streaks in the petals: iron and ammonium sulphate; aluminum phosphate; iron citrate and citric acid. The maroon carnation, when fed with ferrous sulphate, also showed this same tendency. The petals of a white carnation, when the plant was fed with potassium and aluminum sulphate, showed a tendency to form red streaks.

There was a disposition on the part of the plants treated with potassium cyanide to produce less chlorophyl. In the case of the roses and pansies the leaves were beautifully variegated; in one of the roses growing in sand the edges of the leaves were red, the veins green and the remaining portion yellow. An insufficient supply of iron is generally supposed to produce a paling of leaves, but our observations have not confirmed this. This would tend to show that in certain plants iron is not as necessary as is commonly supposed.

The chief difficulty in experiments of this kind is to achieve and maintain exact control conditions. My work may now be said to be approaching these conditions, and my previous experiments must be regarded as more or less preliminary. It is well known that, when plants grow in a soil containing excessive amounts of copper or zinc, the plants take up these elements, and this demonstrates that the plant will take up certain chemicals under certain conditions, whether they assimilate these or not or whether they are poisoned by them. Until we can establish control conditions whereby we can determine the effects of each substance supplied the plant on different parts of the individual plant, we shall not be able to say just what is the effect of a chemical under varying conditions.

In the interesting experiments of Hoffmann already referred to, on the zinc violet, while he is inclined to consider that individual variation may account for its variability in color, still he says that possibly a difference in climate or physical character of the soil may have influenced the results. While the plant has certain inherent qualities or tendencies which are more or less difficult to

influence, and which perhaps can not be modified except within certain limits without injuring the plant, still, by reason of the more or less unspecialized character of the protoplasm, the plant is more or less plastic and susceptible of modification in various ways, and who can say just what the limits are in any one direction? At least we should not allow ourselves to become dogmatic with regard to this problem. As already enumerated, the external factors influencing color in plants are light, temperature, and soil, including certain atmospheric conditions both physical and chemical. When as much work has been done along these lines as in selection and hybridization, we shall probably understand much better than we do now the causes influencing the variation in the colors of plants.

ARTIFICIAL COLORING OF FLOWERS

A few years ago a gentleman traveling in Italy saw a pink iris in one of the florist's establishments which interested him very much and which he desired to purchase. He then learned that the iris had been artifically colored, and that that particular plant was not for sale. He was, however, able to purchase some of the solution for coloring the flowers, but found to his disappointment on arriving home that the solution did not work.

Within the past year or two quite a demand has been created for green carnations on St. Patrick's day. During the course of my experiments it occurred to me that it might be possible to take a plant which was deficient in coloring matter and add to it the extracted coloring matter from some other plant. There is a record that as early as 1709, Magnol colored the flowers of tuberoses by placing the stems in the red juice of poke-berries. Even the botanist Unger (1850) stated that the white flowers of the hyacinth could be colored by adding poke-berry juice to the soil. I have been unable to confirm these observations by the use of any natural coloring substance. For nearly fifty years various artificial coloring substances have been used in the study of the ascent of cell-sap. While considerable attention has been given to the ascent of these substances in the stem, not much attention has been given to their effects on flowers, although here and there in the literature one will find a statement with regard to certain effects of this kind.

In addition to experimenting with vegetable coloring matters, I have experimented with quite a large number of aniline dyes, and have obtained some rather striking results. These dyes are readily soluble in water, and the solutions are made up of a strength of 1 part of dye to 1,000 parts of water. The effects are best seen in white flowers and are produced by allowing the flower-stalks to remain in the solutions from one to two hours, when they are placed in water. With some flowers, as the cultivated anemones, the effects are noticeable in from ten to fifteen minutes. The results show that some flowers will take up the dyes better than others, and also that only a comparatively few of the thousands of aniline dyes can be utilized for the coloring of flowers. These belong chiefly to the classes of azo and rosaniline coloring matters, the acid dyes or those used for dyeing wool producing the best effects. White flowers may be changed to yellow, orange, blue, green, purplish-red or magenta, crimson, purple, salmon-pink or gray by the use of the following dyes:

1. Yellow flowers are produced by the use of the dye known commerically as "Acid Yellow A. T.," which is chemically the sodium salt of disulpho-diphenylazin-dioxytartaric acid.

2. Orange-colored flowers may be produced by the use of the dye "Orange G. G.," which is the sodium salt of benzene-azo-B-napthol-disulphonic acid.

3. Blue flowers may be produced by the use of the dye "Cyanol F. F.," which is the sodium salt of meta-oxy-diethyl-diamido-phenyl-ditolyl-carbinol-disulphonic acid.

4. Green flowers may be produced by the use of equal parts of the dyes "Acid Yellow A. T." and "Cyanol F. F."

5. Purplish-red flowers are produced by the use of the dye "Acid Magenta," which is the sodium salt of the trisulphonic acid of rosaniline.

6. Crimson flowers may be produced by the use of equal parts of the dyes "Acid Yellow A. T." and "Acid Magenta."

7. Purple flowers may be produced by the use of equal parts of "Cyanol F. F." and "Acid Magenta."

8. Salmon-pink flowers may be produced by the use of the dye "Brilliant Croceine M. O. O.," which is the sodium salt of benzene-azo-benzene-azo-B-naphthol-disulphonic acid.

9. Gray flowers may be produced by the use of the dye "Naphthol Black B.," which is the sodium salt of disulpho-B-napthalene-azo-A-napthalene-azo-B-naphthol-disulphonic acid.

I have also tried feeding these solutions to the growing plants, and found that carnations growing in an artificial soil, the basis of which is sand, will take up the solutions and show the effects in the flowers. The dyes are taken up chiefly through the tissues of the veins and are gradually diffused in the adjoining cells. The plants are not injured by the solutions, and if they are properly used neither the texture nor odor of the flowers is affected.

While the artificial coloring of flowers in the manner described is of more or less interest from the scientific point of view, it has also a practical application. In decorative schemes where a particular color is selected this method could be used for producing flowers all of one color, such as blue roses, blue carnations along with violets and other blue flowers. Or in some instances, where the demand for flowers of a certain color is greater than the supply, artificially colored flowers could be produced from white ones.

These dyes may also be used to intensify flowers having a pale color at this season of the year, as pale-yellow carnations, pale-pink roses, pale-yellow snap-dragon, etc. In some cases the natural colors can be modified, as in the production of yellowish-red flowers of snap-dragon from yellow flowers. In the production of novelties, as in the production of green carnations and green roses, the method can be utilized. The color produced by Naphthol Black B. is a delicate gray or grayish-black, and it has been suggested that roses and carnations colored with this dye would furnish appropriate mourning flowers. Another use of these dyes is in the coloring of wild flowers for decorative purposes. For example, wild carrot when colored with a blue dye gives a beautiful effect, being suggestive of a head of forget-me-nots.

The colors of flowers so dyed are permanent, and the dried flowers can in some instances be used for ornamental purposes, as in the case of hydrangeas, which are frequently used in the dried condition. There may be a possible application of these results in the manufacture of artificially colored dried flowers and plants for decorative purposes.

SUMMARY

My observations on the subject of color in plants, may be summarized as follows:

1. There are two classes of color-substances in plants:

(*a*) Organized color-principles which are characterized by being an organic part of the plastid body, and insoluble in water or dilute alcohol, but soluble in xylol and similar solvents.

(*b*) Unorganized color-principles, which are not a fundamental or organic part of the plastids, and occur either in the vacuoles of the cells of higher plants as well as fungi, or in the vacuolules of the plastids of the brown and red sea-weeds. They are further distinguished by being soluble in water and dilute alcohol, and insoluble in xylol and similar solvents.

2. The plastid pigments, or organized color-substances, may be divided into three groups according to their origin.

(*a*) Chlorophyl, which occurs in the chloroplastids in both higher and lower plants, and is especially distinguished by the appearance of its solution when viewed by means of the spectroscope.

(*b*) Chromophyl, which occurs in the chromoplastids, plastid bodies which are peculiar to the higher plants. The chromoplastids together with the accompanying pigment are found in many flowers, in certain roots, and follow the development of the chloroplastids in the ripening of many fruits.

(*c*) Etiophyl, which is found in an etioplastid occurring in the palisade-cells of the innermost leaves of the leaf-bud of *Spathyema foetida*. It is distinguished from chromophyl by becoming slightly greenish when reduced with zinc. The etioplastid is distinguished from the chromoplastid by the fact that its development precedes that of the chloroplastid.

3. In the photosynthesis of the chloroplastid, unorganized color-substances may be produced in comparatively large amount, as in

(*a*) Early spring foliage;

(*b*) The foliage of alpine plants as well as autumnal foliage;

(*c*) The brown and red marine algae;

(*d*) The foliage of certain species or varieties of rose, beech, nasturtium; etc.

4. Unorganized or cell-sap color-substances are distributed

usually in largest amount at the termini of the branches, as in flowers and terminal leaves, or in roots, or in both tops and roots. Their occurrence in those portions of the plant which are young and growing, points to the conclusion that they are not to be disregarded in the study of metabolic processes. Goebel likewise holds to this view. He says that it is "very probable that the feature of color which so often appears when the propagative organs are being brought forth has some connection with definite metabolic processes, although up till now we cannot recognize what these are."

5. The distribution of the so-called flower color-substances in other parts of the plant than the flower also points to the same conclusion, and that the part which they play in attracting insects to flowers is incidental rather than fundamental. (The fact that certain colored flowers as in spruce are pollinated by the wind, would tend to confirm this view.)

6. The occurrence of chromoplastids in a reserve organ, as in the tuberous root of carrot, and the similar occurrence of chromoplastids and of reserve starch in the petals of the buttercup, lead to the inference that the petal of the buttercup, like the root of the carrot, has the function of storing nutrient material. In each case cells containing chromoplastids rich in nitrogenous substances are associated with cells containing reserve materials.

7. The feeding of plants with chemicals or color-control solutions has not so far, in my hands, produced any marked changes in the colors of the flowers, only some slight effects being noted which might be attributed to other causes. Knowing that plants have a certain individuality and certain inherent qualities or tendencies, one could hardly expect other than negative results. On the other hand we know that the plant is a rather plastic organism, and for this reason we are more or less justified in carrying on experiments along the line indicated.

The fact that of thousands of dyes or color-substances only a few are taken up by the plant and carried as high as the flower, would tend to the probability that only certain chemicals or substances would be taken up and thus exert an influence upon the coloring matter in the flower. If such profound changes arise in plants as are provided by the mutation theory, is it too much to

suppose that certain definite changes may be produced by means of which we have knowldege or control?

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